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Original Articles

Three-Dimensional Analysis of the Proximal Humeral and Glenoid Geometry using MicroScribe 3D Digitizer

3D Proximal Humeral and Glenoid Morphology

Wejdan H. Owaydhah[1,2], Mohammad A. Alobaidy[1,3], Abdulrahman S. Alraddadi[1,4] and Roger W. Soames[1]

[1]Centre for Anatomy and Human Identification (CAHID), School of Science and Engineering, University of Dundee, Dundee DD1 5EH, UK.

[2]Department of Anatomy, Taibah University, Medina, Kingdom of Saudi Arabia.

[3]Department of Anatomy, Faculty of Applied Medical Science, Umm Al-Qura University, Makkah, Kingdom of Saudi Arabia.

[4]King Saud bin Abdulaziz University for Health Science, Riyadh, Saudi Arabia.

Correspondence to: Mohammad Alobaidy, Centre for Anatomy and Human Identification (CAHID), School of Science and Engineering, University of Dundee, Dundee, DD1 5EH, UK. E-mail: m.alobaidy@dundee.ac.uk, maobaidy@uqu.edu.sa. Telephone: +44 1382 388825

Disclaimer: "none"

Ethical Approval: As the study was conducted on cadaveric material relevant consent had been obtained at the time of body donation in accordance with the Human Anatomy (Scotland) Act 2006.

Informed Consent: Obtained prior to and at the time of body donation.

Conflict of Interest: None of the authors have any conflict of interest with the content of this manuscript.

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Abstract:

Purpose: To understand the geometry of the proximal humerus and glenoid fossa to facilitate the design of components used in shoulder arthroplasty. The aim is to evaluate the geometry of the proximal humerus and glenoid fossa and their relationship using a MicroScribe 3D digitizer. Methods: Scans and measurements were obtained from 20 pairs of dry proximal humeri and scapulae (10 female, 10 male cadavers: median age 81 years (range 70 - 94 years)) using a MicroScribe 3D digitizer and Rhinoceros software. Results: Means (± SD) of humeral inclination, medial wall angle of the bicipital groove and radius of the humeral head values were $135 \pm 11°$, $39 \pm 19°$ and 14 ± 3 mm, respectively. Means (± SD) of glenoid height and width were 35 ± 4 mm and 26 ± 4 mm, while the means (± SD) of the angles of glenoid inclination, retroversion and rotation were $87 \pm 32°$, $96 \pm 10°$ and $9 \pm 6°$ respectively. A significant difference in glenoid height ($P \leq 0.002$) and width ($P \leq 0.0001$) was observed between males and females, despite them having almost an identical radius of the humeral head, glenoid inclination, retroversion and angle of rotation. There was also a significant difference ($P \leq 0.01$) in the angle of glenoid retroversion between the right and left sides. Conclusions: Using a MicroScribe 3D digitizer the glenoid fossa was observed to be significantly smaller in females than males, furthermore there was a difference in glenoid retroversion between the right and left sides.

Keywords: Glenoid, Proximal humerus, MicroScribe 3D digitizer, Shoulder, Rhinoceros software.

Introduction

The head of the humerus is approximately one-third of a sphere articulating with the glenoid fossa forming the glenohumeral (shoulder) joint [17]. The proximal humerus is continuous with the shaft at the surgical neck distal to the lesser and greater tuberosities: the anatomical neck lies above the tuberosities [17]. The bicipital groove is present between the lesser and greater tuberosities, extending distally some 5 cm [18] on the anterior aspect of the proximal shaft. The greater and lesser tuberosities are oriented laterally and anteromedially with the greater tuberosity giving attachment , from superior to inferior to supraspinatus, infraspinatus and teres minor, and the lesser tuberosity to subscapularis. These four muscles help provide stabilization of the humeral head against the glenoid [17].

The scapula is a flat, triangular bone with two surfaces, three angles and three borders, and forms the most posterior portion of the shoulder girdle [17]. The glenoid fossa presents as the lateral angle of the scapula, with the intraarticular supraglenoid tubercle close to the base of the coracoid process and the extraarticular infraglenoid tubercle below the glenoid fossa [2]. The slightly concave, shallow glenoid fossa is covered by hyaline cartilage: it may be oval, shaped like an inverted comma or be pear-shaped [17], with the most common form being pear-shaped (49% and 46% on the right and left respectively [19]).

The aims of the current study were: (i) to evaluate the geometry of the proximal extremity of the humerus and glenoid fossa, and (ii) determine the relationship between them. Consequently, specific parameters of the humeral head (humeral inclination angle, medial wall angle of the bicipital groove, radius of the humeral head) and glenoid fossa (glenoid inclination, glenoid retroversion and glenoid rotation) were determined.

Materials and Methods

Twenty pairs of the proximal extremities of humerus and scapulae from 10 female and 10 male formalin embalmed cadavers were harvested and examined: the median age of the specimens was 81 years (range 70 to 94 years). Each specimen was scanned (resolution 1000 μm) using a hand-held Microscribe 3D digitizer (Immersion, San Jose, CA, USA) (Fig. 1a). Measurements were taken by touching the specific bony landmarks , with the data being directly entered into the Rhinoceros modelling software and presented graphically.

Intraobserver and interobserver reliability tests were carried out to assess the validity of the methodology: measurements were taken on a random selection of landmarks on three separate occasions of three specimens by the same individual for the intraobserver test, and by three individuals for the interobserver test. The Cronbach reliability coefficient for the intraobserver and interobserver reliability tests was compared using the George and Mallery [9] scale (> 0.9-Excellent, > 0.8-Good, _> 0.7-Acceptable, > 0.6-Questionable, > 0.5-Poor, and < 0.5-Unacceptable).

The following measurements were obtained:

a) Humeral inclination angle (HI) was defined as the orientation of the humeral head relative to the shaft. Based on Harrold and Wigderowitz [10], the humeral inclination angle was determined as the angle between the humeral shaft axis (B1 and B2) and a line drawn between points C1 and C2 (Fig. 1b).

3D Proximal Humeral and Glenoid Morphology

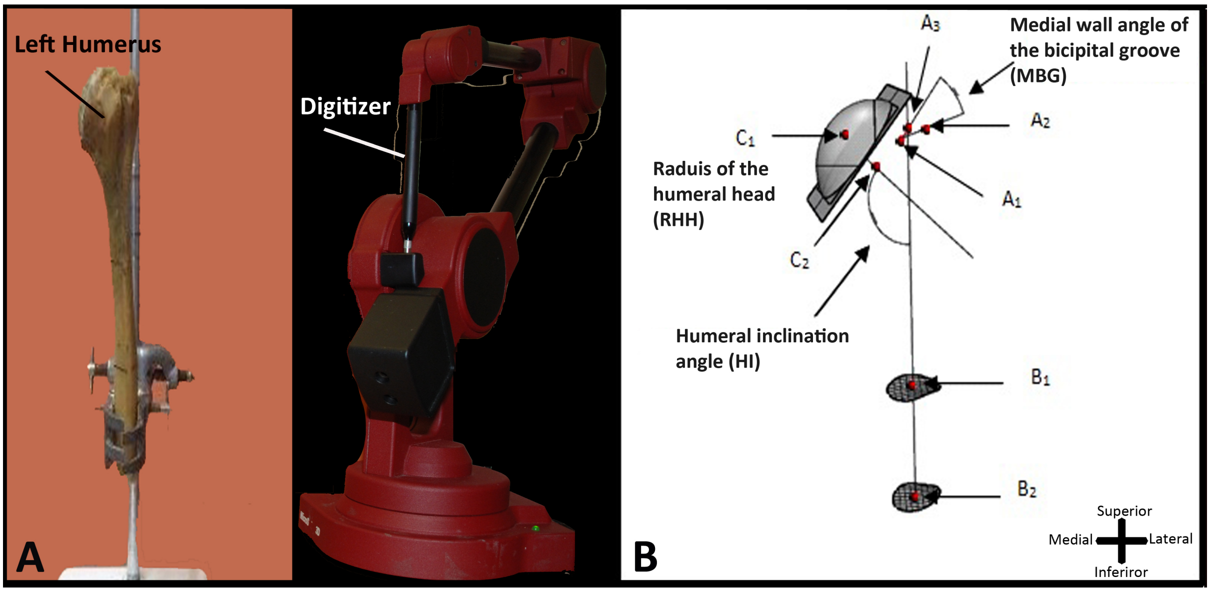

Fig. 1 A: The MicroScribe 3D digitizer, (Immersion Corporation, San Jose Ca, USA). B: Model constructed of the proximal humerus in Rhinoceros modelling software showing annotated description of humeral measurements. B1- B2, the shaft axis; RHH, radius of the humeral head; HI, humeral inclination angle; MBG, medial wall angle of the bicipital groove; C1-C2, line between centroid area of head and centroid area of articular surface; A1-A2 line between lesser and greater tuberosity; A1-A3, line between lesser tuberosity and proximal point of the bicipital groove.

b) Medial wall angle of the bicipital groove (MBG) was determined as the angle between a tangent to the superior margin of the lesser and greater tuberosities (A1 and A2) and a tangent to the medial wall of the intertubercular sulcus of the bicipital groove (A1 and A3) (Fig. 1b) [7].

c) Radius of the humeral head (RHH) was taken as the length of the line between C1 and C2 (Fig. 1b) [10].

d) Based on Strauss et al [21], glenoid height (GH) was measured as the distance between the most superior and inferior points of the glenoid cavity, and width as the distance between the most anterior and posterior points of the glenoid margin (Fig. 2a).

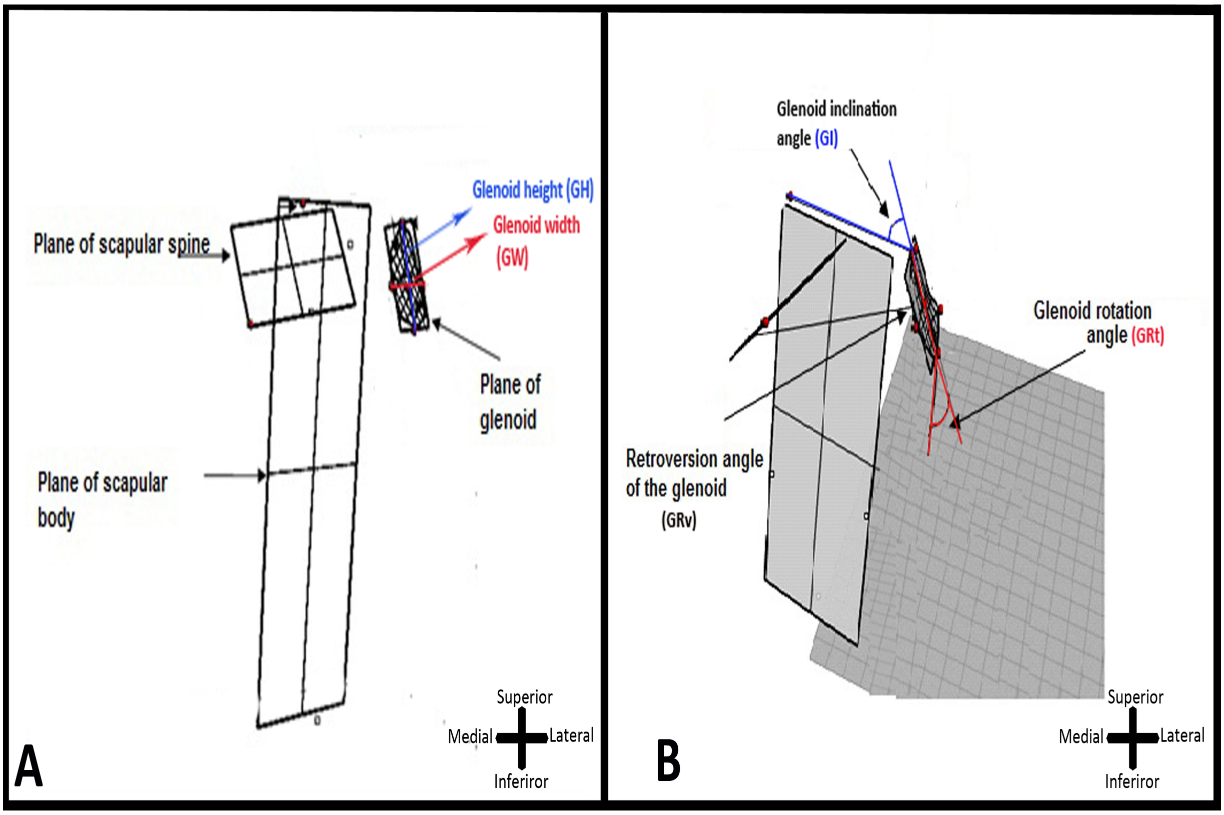

Fig. 2 A: Model constructed of the scapula in Rhinoceros modelling software, and GH, glenoid height; GW, glenoid width. B: Annotated description of glenoid parameter measurements; GI, glenoid inclination angle; GRt. Glenoid rotation; GRv, glenoid retroversion angle; line perpendicular to the line that extends between the centroid area of the glenoid cavity and the point marked on scapula where the scapular spine meets the medial border of the scapula.

e) Glenoid inclination angle (GI) was based on Kandemir et al [13], being between a line connecting the superior and inferior points of the glenoid margin and a line connecting the most superior parts of the glenoid margin and scapular blade medial to the suprascapular notch (Fig. 2b).

f) Glenoid retroversion (GRv) was again based on Kandemir et al [13], being the angle between a line connecting the most anterior and posterior points of the glenoid margin and a perpendicular line connecting the area where medial border of the scapula meets the scapular spine to the centre of the glenoid (Fig. 2b).

g) Glenoid rotation (GRt) was determined as the angle between the superior and inferior points on the glenoid margin and a line vertical to the glenoid (Fig. 2b).

Exclusion criteria: If the proximal humerus and/or glenoid fossa showed evidence of fracture and/or previous surgery they were excluded from the study.

Statistical analysis: The collected data were analysed using SPSS v16.0 on Windows 7 (IBM Corp, Armonk, NY, USA). Cronbach's alpha coefficient was used to determine internal consistency of the data. Means and associated standard deviations were used for descriptive statistical analysis. One way ANOVA was used to compare the mean values for glenohumeral geometry to test for differences between sex and side, with the level of significance set at $P \leq 0.05$. Pearson correlation coefficients were used to measure the relationship between the glenoid inclination, retroversion and rotation angles, as well as the angle of the bicipital groove and radius of the humeral head.

Results

Cronbach's coefficient for the intraobserver and interobserver tests was 0.92. As indicated by the George and Mallery [9] scale >0.9 is excellent: the measurements therefore had high internal consistency.

The means and associated standard deviations (SD) for each parameter, together with the corresponding values for the right and left sides and for males and females are presented in Table I. A significant difference in mean glenoid height ($P \leq 0.002$) and width ($P \leq 0.0001$) was observed between males and females, as well as a significant difference ($P \leq 0.01$) in glenoid retroversion between the right and left sides.

Pearson correlation coefficients showed several significant relationships (Table II), these being between (i) glenoid inclination and rotation, (ii) glenoid rotation and retroversion, and (iii) glenoid width and medial wall angle of the bicipital groove. A positive significant correlation was observed in males between radius of the humeral head and glenoid inclination ($P \leq 0.02$): in addition, there was also a positive significant correlation between glenoid height and glenoid retroversion ($P \leq 0.03$). In females there was a negative significant correlation between right glenoid rotation and glenoid inclination ($P \leq 0.04$), and a positive significant correlation with glenoid retroversion ($P \leq 0.01$). Right glenoid width and medial wall angle of the bicipital groove were negatively correlated in females ($P \leq 0.04$).

Discussion

The observations in the current study are similar to those reported previously; however some differences were observed possibly due to the different methodologies employed in the various studies. Nevertheless, the data obtained using the MicroScribe 3D digitizer and Rhinoceros software correspond with previous studies of similar measured parameters.

The current study has shown that glenoid height and width vary between males and females, as well as glenoid retroversion between the sides. The form difference is not surprising given the generally larger size of males, while the latter finding may be related to handedness, although no data on handedness of the donors was available to substantiate this. Somewhat surprisingly no significant difference in humeral geometry was observed between males and females. A number of significant correlations between parameters were also observed, these being glenoid rotation and glenoid inclination, and well as between glenoid rotation and glenoid retroversion. It is interesting to note that in males, the radius of the right humeral head was correlated with glenoid inclination, while the radius of the left humeral head was correlated with glenoid retroversion: there is no obvious explanation for this difference.

Robertson et al [20] reported no difference between males and females in humeral inclination angle, their mean value being 41 ± 3^{o} much smaller than in the present study; however they did observe a significant difference between right and left sides. This difference is probably results from the definition of inclination used in the two studies: Robertson et al [20] used a least square fit to determine the articular margin (anatomical neck) and the angle with the canal axis, while in the current study the angle was taken as that between the axis of the shaft and a line between the centre of the head and centroid of the articular surface.

However, the mean humeral inclination angle relative to the axis of the shaft reported here is similar to previous reports [3, 11, 10].

Hitchcock and Bechtol [12] were the first to determine the medial wall angle of the bicipital groove, using it to confirm that subluxation and dislocation of the bicipital tendon increase with a small medial wall angle. Cone et al [7], using a radiographic method, reported an angle of 56°, which larger than in the current study using a 3D method ($39 \pm 19^{\circ}$).Vettivel et al [22], using a goniometer, reported a significant difference in medial wall angle on the right and left sides, while Abboud et al [1], using MRI, reported a mean value of 47° (range 30° - 77°), greater than in the current study: these differences probably reflect the methodologies employed.

The radius of the humeral head determined in previous studies is quite variable. Boileau and Walch [3] reported it as 46.2 ± 5.4 mm, significantly larger than that observed in the present and other studies. Although these authors used a similar method to determine the radius of the head, they measured it in both the coronal and axial planes. The mean radius of the head in the present study (14 ± 3 mm) was less than that reported by Wirth et al., (2007) [24] and Harrold and Wigderowitz [10], being 17 mm and 16.9 ± 1.5 mm respectively.

Churchill et al [6] examined glenoid size, inclination and version on dry scapula. As in the present study, they found a significant difference in mean glenoid height and width between males and females; however no difference was observed in inclination or retroversion. Both studies used the same method to determine retroversion, but a different method for inclination in which Churchill et al [6] turned the scapula 90° and measured from the superior to the inferior glenoid rim. In their anatomic study Merrill et al [16], using digital callipers, reported significant differences in mean glenoid height and width between males and females, again as in the present study. However, in contrast they also reported significant differences in glenoid height and width between the right and left sides. This latter finding may be due to the different measurement procedures used: electronic callipers in their study and a 3D technique in the current study: furthermore, Merrill et al [16] determined glenoid width at different levels from the most superior point of the glenoid.

Mallon et al [15] reported glenoid height and width as 39 ± 4 mm and 28 ± 2 mm for males, and 37 ± 3 mm and 23 ± 2 mm for females. Compared to those in the present study, males glenoid height and width were similar, while female glenoid height was smaller and width greater than in Mallon et al [15]. This difference may be due to the measurement protocols used in defining glenoid width: Mallon et al [15] used the distance between two sagittal planes of the glenoid fossa, whereas in the current study the width was taken between the most anterior and posterior points. Similar to the current study, Mallon et al [15] also reported significant differences in glenoid height and width between males and females, but also observed no difference in glenoid rotation between males and females. The comparisons and disagreements between the current study and that of Mallon et al [15] is most likely due to the methodologies used: Mallon et al [15] determined glenoid rotation between superior and inferior lines of the glenoid fossa and a vertical line from the inferior point of the glenoid fossa, whereas in the current study the angle was taken as being between superior and inferior lines and the scapula blade.

Similar mean values of glenoid height in males and females were reported by Checroun et al [5], in contrast to the significant differences in the current study. The observations of Kandemir et al [13] with respect to glenoid inclination and retroversion were similar to the current study. Interestingly, previous studies have not evaluated whether there were differences in glenoid height and width between the right and left sides or between males and females [10, 14, 23].

Finally, Bokor et al [4] used computerised tomography to determine glenoid retroversion in the coronal plane and the same technique as in the current study to determine retroversion using Friedman's technique. Bokor et al [4] considered the glenoid to be anteverted if the angle was more than 90^{o} and retroverted if it was less than 90^{o}, with their range of glenoid version being 92-102^{o}, narrower than the 47.3-117.4 ^{o} observed in the current study. A significant difference between right and left sides was observed in the current study: Bokor et al [4] did not determine whether there were differences in retroversion between the right and left sides or between males and females.

As stated earlier it was not possible to collect information on handedness or on occupation of the specimens examined in the current study: both may have influenced the bony geometry. Consequently, in future studies it is recommended that such data is included. Comparison of the data collected in the current study shows similarity in the values of some parameters, which is encouraging and suggests that a MicroScribe 3D digitizer and Rhinoceros software can be used to collect relevant data, as well as evaluate the relationship between anatomical features of the proximal humerus and glenoid fossa. To our knowledge this is the first time that such data has been collected for the glenoid fossa, and relationships between the proximal humerus and glenoid fossa reported.

It is apparent that novel data collection and analysis techniques can provide useful information and improve the understanding of bony geometry, and as such could be used in areas where it is important to know and understand the bony geometry. The variations of humeral and glenoid geometry reported here will add to the knowledge necessary in designing future glenohumeral components to ensure a successful reconstruction and outcome.

In conclusion the current study has shown that glenoid height and width vary significantly between males and females, despite their having a similar humeral head radius, glenoid inclination, glenoid retroversion and glenoid rotation. Furthermore, glenoid retroversion was observed to vary between the right and left sides, an important consideration in arthroplasty.

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